

1 TEMPERATURE COMPENSATED VOLTAGE SUPPLY CIRCUIT

2 BACKGROUND OF THE INVENTION

3 1. Field of the Invention

4 The present invention relates to a temperature compensated voltage
5 supply circuit, in particular to a technique and circuit to develop a temperature
6 compensated voltage from two or more base voltages having different
7 temperature coefficients without using complicated modulation processes and to
8 convert a positive temperature coefficient to a negative temperature coefficient to
9 suit wider applications.

10 2. Description of Related Arts

11 In circuit designs, a reference voltage is often an input voltage that is
12 invariant to changes in temperature, which means the temperature coefficient
13 (TC) of the reference voltage has a zero value, where the temperature coefficient
14 (TC) can be defined by the expression:

$$15 \quad TC = \frac{\frac{F(T_2) - F(T_1)}{F(T_0)}}{T_2 - T_1}$$

16 Where:

17 F() function represents a parameter, which is a voltage in the present
18 example;

19 T₀, T₁, and T₂ represent different temperature values, and T₀ is a
20 reference temperature; and

21 F (T₀), F (T₁), and F (T₂) represent three voltages having three different
22 temperatures.

23 However for certain special requirements, the voltage value is expected

1 to vary in accordance with any temperature variation (in which case the
2 temperature coefficient is not a zero value), and the temperature coefficient needs
3 to be controllable. The most important point is that the output voltages at the
4 reference temperature (T_0) must always be the same even with different
5 temperature coefficients. With reference to Fig. 7, the characteristic curves of
6 two different temperature coefficients (TC_1 , TC_2) show that TC_1 value eventually
7 exceeds TC_2 , but their output voltages are all equal to V_0 at the reference
8 temperature T_0 .

9 This circuit design is commonly found in the liquid crystal display (LCD)
10 devices. Since a LCD device is generally sensitive to temperature, the control
11 voltage has to be precise to match the changes in temperature for the precision
12 operation in an LCD device.

13 With reference to Fig. 8, a bandgap reference circuit can be used to
14 control the temperature coefficient by limiting the current passing through a
15 diode, represented by the following expression:

$$16 \quad I = I_o \times e^{\frac{V}{\frac{KT}{q}}} = I_o \times e^{\frac{qV}{KT}}$$

17 where the output current I_{out} can be expressed as:

$$18 \quad I_{out} = \frac{KT}{q} \times \frac{\ln(N)}{R}$$

19 where N represents the proportion of diode contacting areas between two diodes
20 ($D1$, $D2$); their output voltages V_{out} can be represented as:

$$21 \quad V_{out} = V_{diode} + \frac{R1}{R} \times \frac{KT}{q} \times \ln(N)$$

22 where V_{diode} represents the voltage value across two ends of diode ($D3$).

23 In this model, the output voltage tends to decrease as the temperature

1 rises, but the constant KT/q will increase along with the temperature. Using their
2 complementing characteristics, a suitable reference voltage V_0 can be obtained
3 when the temperature is equal to T_0 .

4 On the other hand, when the ratio between two resistors ($R1/R$) is
5 changed, the output voltage V_{out} will also be changed, which means the
6 temperature coefficient can be used to control the output voltage V_{out} .

7 in, With reference to Fig. 9, the following example employs four
8 bandgap reference circuits to generate output voltages with different temperature
9 coefficient (TC1~TC4). A multiplexer is used to select a particular bandgap
10 reference circuit based on the actual temperature requirement. The output voltage
11 is temperature compensated, and the output voltage is always equal to the
12 reference voltage (V_0) at a reference temperature T_0 . The main disadvantage of
13 using this technique is that these bandgap reference circuits occupy a large space
14 in the integrated circuit and consume considerable power. Therefore, under the
15 precondition that the output voltage has to be equal to the reference voltage (V_0)
16 at a reference temperature T_0 , the most difficult task is finding suitable
17 components having different temperature coefficients to produce different output
18 voltages. This poses a challenge for fabrication of the present day semiconductor.

19 With reference to Fig. 10, another example of a bandgap reference
20 circuit is based on the design described in the previous example, but the two
21 bandgap reference circuits are connected in parallel in this example respectively
22 with output voltages $V1$ and $V2$. To generate voltage values having different
23 temperature coefficients, two diodes ($D1, D2$) are used, which are built with
24 somewhat different processes to produce the necessary temperature

1 characteristics. Unfortunately, this modulation process cannot be implemented in
2 actual chip fabrication.

3 With reference to Fig. 11, another conventional bandgap reference
4 circuit uses a single bandgap reference circuit to generate four different output
5 voltages (V1~V4) having different temperature coefficients. However, the
6 output voltages (V1~V4) are not equal at temperature T_0 . thereby four level
7 conversion circuits are required for tuning the output voltages (V1~V4) to make
8 the voltage values (VTC1~VTC4) converge at temperature T_0 . After the
9 conversion by the level conversion circuit, the output voltages (V1~V4) can then
10 be defined as follows:

11
$$VTC_n = a_n \times V_n + b_n, \text{ where } n=1\sim 4.$$

12 With reference to Fig. 12, still another bandgap reference circuit, is
13 largely based on the previous design, but only two voltage outputs (V1,V2) are
14 generated instead of four. These two output voltages are obtained from two
15 resistors (R1,R2) connected in series. Using the same design logic, four resistors
16 must be connected in series if four output voltages are needed.

17 The biggest drawback in the above design is that the level conversion
18 circuit will complicate the circuit design, which not only takes up more space in
19 circuit design but also uses more power. Furthermore, the temperature coefficient
20 of each output voltage after the level conversion is also likely to be changed.

21 SUMMARY OF THE INVENTION

22 The main objective of the present invention is to provide a method and
23 circuit for developing temperature compensated voltage supply based on two or
24 more base voltages having different temperature coefficients, and also to convert

1 a positive temperature coefficient to a negative temperature coefficient in the
2 voltage modulation process for wider applications.

3 The method comprises the steps of:

4 generating a first base voltage (VTC1) and a second base voltage
5 (VTC2), where the first base voltage (VTC1) and the second base voltage (VTC2)
6 have different temperature coefficients (TC1, TC2) and have the same voltage
7 value at a reference temperature T_0 ;

8 generating an output voltage (V_{new}), based on the first base voltage
9 (VTC1) and the second base voltage (VTC2) assigned with different weighted
10 values (a,b), and this output voltage (V_{new}) must satisfy the following
11 expression:

12
$$V_{new} = a \times VTC2 + b \times VTC1$$

13 where

14 the output voltage (V_{new}) possesses a new temperature coefficient
15 (TCnew); and

16 the two weighted values (a,b) have to satisfy the conditions: $a+b=1$, and
17 $0 \leq |a|, 1 \geq |b|$.

18 The temperature coefficient (TCnew) must satisfy the expression:

19
$$TC_{new} = TC1 + a \times (TC2 - TC1).$$

20 In actual implementation, the circuit for the present invention includes:

21 a base voltage generator for generating two different base voltages
22 having different temperature coefficients (T1,T2), and these two or more base
23 voltages must exhibit the same voltage value at the reference temperature;
24 a output voltage generator for generating an output voltage after

1 summing the two base voltage values, where the output voltage possesses a new
2 temperature coefficient (TCnew) derived from the temperature coefficients
3 (T1,T2) of the two base voltages, and the TCnew has to satisfy the expression:

4
$$TC_{new} = TC1 + a \times (TC2 - TC1).$$

5 The features and structure of the present invention will be more clearly
6 understood when taken in conjunction with the accompanying drawings.

7 BRIEF DESCRIPTION OF THE DRAWINGS

8 Fig. 1 is a circuit diagram of a base voltage generator that employs two
9 base voltages with different temperature coefficients to generate an output
10 voltage in accordance with the present invention;

11 Fig. 2 is a block diagram of an output voltage generator using two base
12 voltages to generate an output voltage;

13 Fig. 3 is another implementation of the output voltage generator using
14 capacitor switching to modulate the temperature coefficients;

15 Fig. 4 is a timing diagram of clock waveforms for controlling the
16 switches used in fig. 3;

17 Fig. 5 is another embodiment of the invention;

18 Fig. 6 is a schematic of the circuit that uses capacitor switching to
19 modulate the temperature coefficients in accordance with the present invention;

20 Fig. 7 is a characteristic curve of two base voltages with different
21 temperature coefficients;

22 Fig. 8 is a schematic of a conventional bandgap reference circuit;

23 Fig. 9 is a block diagram of a conventional voltage supply circuit through
24 modulation of temperature coefficients;

1 Fig. 10 is a detailed circuit diagram of the bandgap reference circuit in
2 fig. 8;

3 Fig. 11 is a block diagram of another conventional voltage supply circuit
4 through modulation of temperature coefficients; and

5 Fig. 12 is a detailed circuit diagram of the bandgap reference circuit in
6 fig. 10.

7 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

8 The present invention provides a circuit and method for developing a
9 temperature compensated voltage supply, which use two base voltages having
10 different temperature coefficients. The output voltage has a new temperature
11 coefficient. The operating principle behind the present invention first sets up a
12 first base voltage(VTC0) and a second base voltage(VTC) having different
13 temperature coefficients. The temperature coefficient (TC1) of the first base
14 voltage (VTC0) is always equal to zero, which means the first base voltage
15 (VTC0) is a constant value invariant to changes in temperature. The second base
16 voltage (VTC) is equal to the first base voltage (VTC0) when the reference
17 temperature (T_0) is reached, which can be represented by the first expression:

18
$$VTC = VTC0 \times [1 + TC \times (T - T_0)] \dots (1)$$

19 Thereafter, an output voltage (V_{new}) is generated using the first base
20 voltage (VTC0) and the second base voltage (VTC), as defined by the second
21 expression:

22
$$V_{new} = a \times VTC + b \times VTC0 \dots (2)$$

23 where parameters (a, b) represent weighted values assigned to the first base
24 voltage(VTC0) and the second base voltage(VTC), and these two weights shall

1 satisfy the conditions: $a+b=1$, $0 \leq |a|$, $1 \geq |b|$.

2 By rearranging the above two expressions and adding a new condition

3 $a+b=1$, the actual output voltage (V_{new}) can be expressed as:

4
$$V_{new} = V_{TC0} \times [1 + a \times TC \times (T - T_0)] \dots (3)$$

5 By comparing the first and third expressions, the temperature coefficient

6 of the output voltage (V_{new}) will become TC_{new} , when the temperature

7 coefficient is equal to $a \times TC$: $TC_{new} = a \times TC$

8 That a new temperature coefficient can be created just by changing the

9 value (a) is apparent from the above description, and if the value (a) is negative,

10 then a new temperature coefficient with negative value is produced.

11 The hardware implementation of the present invention comprises a base voltage

12 generator and an output voltage generator. The base voltage generator generates

13 two base voltages having different temperature coefficients (T_1 , T_2), where the

14 two base voltages are equal at the reference temperature (T_0). The output voltage

15 generator generates an actual output voltage after summing the two base voltages

16 assigned different weights. The temperature coefficient (TC_{new}) of the output

17 voltage is determined by the temperature coefficients (T_1 , T_2) of the two base

18 voltages.

19 With reference to Fig. 1, an actual implementation of the base voltage generator

20 for the present invention generates the first base voltage (V_{TC0}) and the second

21 base voltage (V_{TC}) and includes a current mirror (10), a first output circuit (20)

22 and a second output circuit (30). The current mirror (10) has an output side and an

23 input side. The output side is connected to a resistor (R) and a diode (D)

24 connected in series. The input side has a diode (D_0), The diodes (D , D_0)

1 respectively have contact areas. The contact area of the diode (D) on the output
2 side is N times greater than the contact area of the diode (D_0) on the input side.
3 The first output circuit (20) has an input, a resistor (R1), a diode (D1) and an
4 output. The input is connected in parallel to the output of the current mirror (10)
5 and to a resistor (R1) and a diode (D1) connected in series. The resistor (R1) has
6 an inside end and an outside end. The outside end is connected to the diode (D1),
7 and the inside end is an output node for the first base voltage (VTC0). The second
8 output circuit (30) has an input, a resistor (R2) and an output. The input is
9 connected in parallel to the output of the current mirror (10) and in series to the
10 resistor (R2). The resistor (R2) has an inside end and an outside end. The inside
11 end is an output node for the second output voltage (VTC).

12 To fulfill the above circuit requirements, the ratio of the two resistors
13 (R1, R) has to be adjusted to make the temperature coefficient of the first base
14 voltage (VTC0) equal a zero value to produce a constant voltage value. Then, the
15 resistance of resistor (R2) is adjusted to make the second base voltage (VTC)
16 equal to the first base voltage (VTC0) when the temperature is T_0 , that is $VTC(T_0)$
17 = VTC0.

18 With reference to Fig. 2, an actual implementation of the output voltage
19 generator obtains an actual output voltage (V_{new}) from two base voltages (VTC,
20 VTC0). In this example, two resistors (R3, R4) connected in series are used as a
21 voltage divider to generate an output voltage (V_{new}), where the ratio between
22 two resistors (R3, R4) depends on the parameter (a) in the third expression.
23 Therefore, when the ratio between these two resistors is changed, a different
24 temperature coefficient can be obtained. The main advantage of this design is its

1 simplicity, but the temperature coefficient so obtained still possesses the same
2 positive and negative characteristics as the base voltages (VTC0, VTC).
3 Therefore, a positive voltage value cannot be converted to a negative voltage
4 value in this case.

5 With reference to Fig. 3, another method for generating an actual output
6 voltage (Vnew) uses capacitor switching. The circuit employs four switches (S1,
7 S3, S21, and S22) and three capacitors (C1~C3). The first capacitor (C1) has two
8 ends that are respectively connected to switches (S1, S21) leading to a first base
9 voltage (VTC0), and one end is also connected to a second base voltage (VTC)
10 through another switch (S22).

11 The second and third capacitors (C2, C3) are connected in parallel to the
12 first capacitor (C1), with a switch (S3) mounted between the second and third
13 capacitors (C2, C3). One end of the third capacitor (C3) becomes a node for
14 output voltage.

15 With reference to Fig. 4, a clock sequence with three non-overlapping
16 clock signals (P1-P3) controls the operation of the four switches (S1, S3, S21,
17 and S22).

18 Determining whether the positive and negative values of the new
19 temperature coefficient are to be the same or different from the original
20 temperature coefficients is possible with this capacitor switching technique.

21 (a) The values of the temperature coefficient on the output voltage (Vnew) and
22 the original temperature coefficients on the first and second base voltages are
23 both positive or both negative when the clock signals (P1-P3) for the switches
24 (S1, S3, S21, and S22) are:

1 $S1=P1$

2 $S3=P3$

3 $S21=P1$

4 $S22=P2.$

5 (b). The values of the temperature coefficient on the output voltage (V_{new}) and
6 the original temperature coefficients on the first and second base voltages are
7 positive and negative (i.e. opposite signs) when the clock signals ($P1-P3$) for the
8 switches ($S1, S3, S21$, and $S22$) are:

9 $S1=P1$

10 $S3=P3$

11 $S21=P2$

12 $S22=P1.$

13 By changing the ratio between the two capacitors ($C1, C2$), which
14 generates a different weighted value (a), the output voltage (V_{new}) can be made
15 to have a new temperature coefficient value.

16 With reference to Fig. 5, another embodiment of the present invention
17 has a first base voltage (V_{TC1}) and a second base voltage (V_{TC2}) with
18 individual temperature coefficients ($TC1, TC2$) not equal to zero, and the first
19 and second base voltages (V_{TC1}, V_{TC2}) must be the same at a reference
20 temperature T_0 . The new temperature coefficient (TC_{new}) on the output voltage
21 (V_{new}) can be expressed as follows:

22 $TC_{new} = TC1 + a \times (TC2 - TC1).$

23 With reference to Fig. 6, the resistive circuit can be modified by
24 implementing the previously described capacitor switching technique, where the

1 switches (S1, S3, S21, and S22) use the same clock signals (P1-P3) previously
2 described to control the switching to generate either a positive or negative
3 temperature coefficient.

4 From the foregoing, the circuit design of the present invention is much
5 simpler than the conventional methods, by summing two base voltages with
6 variable temperature coefficients to generate an output voltage. The voltage
7 supply circuit also takes up less space and consumes less power.

8 The foregoing description of the preferred embodiments of the present
9 invention is intended to be illustrative only and, under no circumstances, should
10 the scope of the present invention be so restricted.